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Predicting impacts of climate variability on habitats of *Hippophae salicifolia* (D. Don) (Seabuckthorn) in Central Himalayas: Future challenges

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ABSTRACT

Climate variability is the most influential driver altering the natural habitats of species leading to worldwide biodiversity loss. Understanding the climatic niche of vulnerable species and predicting its shift due to impending climate change is highly important to assess the damage. It also helps to plan and implement long term ex-situ or in-situ strategies to protect the species and its fragile habitats. Though, various important species of Himalayas are exploited for their economic and medicinal benefits, yet the impact of climate change on species have not been efficiently documented. Present study, is an attempt to understand the impact of climate vulnerability on habitat suitability of *Hippophae salicifolia*, a multipurpose species that grows particularly on the riparian fronts of river Ganga in Central Himalayas, using species distribution modeling. The Maximum entropy (MaxEnt) model with field observed occurrence locations of the species and CMIP5 (Couple Model Inter-comparison Project) derived bioclimatic variables were used for the study. The predictions were done on the geographic area of Central Himalayas in Uttarakhand state of India according to four IPCC RCPs (Intergovernmental Panel for Climate Change, Representative Concentration Pathways) for the future periods 2050 and 2070. Our results show that the estimated potential (threshold-1) area along the riparian fronts is around 2050 km^2 for the current period. Whereas, for the future years, the suitable area is likely to be lost by 87% for all climate change scenarios making *H. salicifolia* highly vulnerable in it' s actual habitats. An upward shift in the habitat of the species by 1700 m amsl (2800–4500 m amsl) is also predicted. Shift of species from its micro-habitats due to climate reflects unusual patterns and demands the vital need of applying climate adaptive management for habitat conservation. Present study presents a baseline database for broad-scale applicability of riparian front restoration for species conservation.

1. Introduction

Biodiversity supports the ecosystem services and it in turn fosters human well being and climate resilience (Pereira et al., 2012, 2013). Though, there is serious international commitment to protect biodiversity, its depletion is not slowing down (Butchart et al., 2010). Ecosystems across Asia are threatened by an array of direct and indirect drivers, each of which have potential to damage the biodiversity (Hughes, 2017). Climate change and global warming is a warning call for entire planet and a well-acknowledged fact by scientists (Lindner et al., 2010). South Asia is experiencing frequent extreme climate events and the increase in temperature is going to be way beyond the reported mean global temperature (Christensen et al., 2007; Kumar et al., 2011). Cumulative effects of climate led variability and anthropogenic interferences have already started affecting the distribution of many species (Anderegg et al., 2015; Coetzee et al., 2009; Malcolm et al., 2006).

Loss of species, leads to loss of natural processes that influence the flow of ecosystem services (De Leo and Levin, 1997). Species loss is not going to be limited to spatio-temporal scales but is also going to affect trophic structures and their interactions (Hector et al., 2001). So far it has already been proved that impact of climate variability is going to severely affect species distribution (Hughes, 2000; Parmesan, 2006; Peterson et al., 2005; Root et al., 2005), and species extinction (Thomas et al., 2004; Walther et al., 2002), that ultimately results in reduced flow of ecosystem services (Diaz et al., 2015; Millennium Ecosystem

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Nomenclature

AUC	Area Under Curve
CCSM4	The Community Climate System Model Version-4
CMIP5	Coupled Model Inter-comparison Project Phase-5
DEM	Digital Elevation Model
EcoDRR	Ecosystem based Disaster Risk Reduction)
FSI	Forest Survey of India
GCM	Global Climate Models
HEP	Hydro Electric Projects
IHR	Indian Himalayan Region
IPCC	Intergovernmental Panel for Climate Change
IUCN	International Union for Conservation of Natural Resources
MaxEnt	Maximum Entropy
MoEF&CC	Ministry of Environment, Forest and Climate Change
NEERI	National Environmental Engineering Research Institute
RCP	Representative Concentration Pathways
SDM	Species Distribution Modeling
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
VIF	Variable Inflation Factors

Assessment, 2005). According to the regional reports of Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (Diaz et al., 2018) and report of Millennium Ecosystem Assessment (2005) > 50% of the global biodiversity is under severe threat to extinction.

Himalayas are well-recognized biodiversity hotspots where ecological and evolutionary processes have supported species richness and diversity (Rastogi, 1993). The fragile landscapes and undulating terrains of the India Himalayan Region (IHR) are highly susceptible to natural hazards and disasters (Dhyani and Dhyani, 2016a). Many parts of IHR are undergoing continuous degradation due to climate led vulnerability (Dhyani and Dhyani, 2016b). Impact of climatic variability on Himalayan ecosystems and flow of ecosystems services is going to be significant and will affect people dwelling both upstream and downstream. Envisaging the probable distribution of species under the scenario of climate change and ongoing anthropogenic interferences will be a relevant approach for planning efficient conservation strategies (Dawson et al., 2011).

Hippophae salicifolia (D. Don) commonly known as Seabuckthorn belonging to family Elaeagnaceae is a deciduous, thorny willow-like plant species (life form is tree with shrub like growth) native to Eurasia that grows in the icy heights (1500–3500 m above sea level) of the trans Himalayas in Jammu Kashmir, Himachal Pradesh, Sikkim and Uttarakhand states of India. *H. salicifolia* is present in riverine areas of inner-montane valleys. Along the freely draining slopes on river banks, *H. salicifolia* often forms pure stands on the freshly formed landslips. The species preferably grows in low humid, alluvial gravel, wet landslides and in riparian zones (Dhyani et al., 2007a). *Hippophae* is a fast growing species that serves for soil conservation and provides innumerous provisioning, regulating and supporting ecosystem services to hill locals. The plant has extraordinary potential to flourish and thrive in extreme temperature conditions (−40 to 40 °C) and grows extensively through root turins. Plant has strong soil binding and atmospheric nitrogen fixing capability that helps soil and slope strengthening, protection of riparian buffers and soil moisture retention (Dhyani et al., 2010; TISC, 2001).

The plant has immense potential to adapt to the stress brought due to high altitude conditions of IHR that includes fluctuating temperature, snow, rain and dry periods (Rathor et al., 2015). During last three decades, *Hippophae* has attracted immense attention from academicians, inventors and ecologists across the globe for its economical and ecological potential. Berries of *H. salicifolia* plant have been considered as treasure of bioactive substances. Approximately, 190 bioactive secondary metabolites and 106 compounds have been extracted from fruit juice and seed oil of *Hippophae* (Chu et al., 2003; Ranjith et al., 2006; Rongsen, 1992). In last few decades several secondary metabolites and phytochemicals present in the plant have attracted many pharmaceutical and nutraceutical industries (Dhyani et al., 2010; Raffo et al., 2004; Sabir et al., 2005; Tiitinen et al., 2006). In modern research for developing novel medicines and personal care products plant has been extensively used for curing modern day ailments (dermal, cardio-vascular, ulcers, gastrointestinal ailments as well as for curing lack of nutrients, sexual abnormality, liver ailments, hepatitis-A, as well as hepatitis-B, and other terminal illness) (Brijlal and Gupta, 2001; Singh and Lal, 2008; Xing et al., 2002; Zeb, 2004). > 200 processing industries spread across the globe are involved in harnessing the species by producing > 200 different products. These products are mostly related to food, beverages, life saving drugs, cosmetics, health tonics, etc. (Gayle, 2008; Lebeda, 2005; Ranjith et al., 2006; Rongsen, 1992). For mountain communities and inhabitants, species offers immense potential and opportunities to maintain sustainable livelihood, nutritional support, medicinal support and protects their slopes from erosion (Ansari, 2003; Dhyani et al., 2010).

Although, *H. salicifolia* is prone to extensive habitat degradation and over exploitation (Dhyani et al., 2013), surprisingly the species falls under “Not Evaluated” category by IUCN (International Union for Conservation of Natural Resources). Overall range and drivers for distribution of *H. salicifolia* remains poorly defined for Himalayan region. The major reasons of habitat degradation are continuous road construction, broadening activities and proposed hydropower projects (Dhyani et al., 2013; Rajvanshi et al., 2012). Exploration, and identification of habitat suitability for *H. salicifolia* under changing climate scenario is a relevant initiative to address the declining species population. Very few studies have been attempted in IHR (Indian Himalayan Region) on understanding the impact of climate change on habitat suitability of ecologically important species (Adhikari et al., 2012; Chakraborty et al., 2016; Pramanik et al., 2018). Our study will be the first attempt in understanding the distribution of *Hippophae salicifolia* under future climate change scenarios for developing conservation and management plan for the species.

Species distribution Modeling (SDM) is a pragmatic instrument in ecology, biogeography, for management of species, their habitat and ecosystems as it characterizes the probable distribution of species population in future, as per diverse variables of environment (Elith et al., 2006; Elith and Leathwick, 2009; Guillera-Arroita et al., 2015; Guisan and Thuiller, 2005; Razgour et al., 2016). The changes in economic value of forest products in Europe (Hanewinkel et al., 2012), redistribution of marine biodiversity (GarciaÂ Molinos et al., 2015), future of citrus fruits (Narouei-Khandan et al., 2016) are few of the key examples of SDM. As a result of its advantages, a number of international organizations have used SDM to tackle strategic policy objectives (e.g., Birdlife International, Convention of Biological Diversity, IUCN, UNEP-World Conservation Monitoring Centre, Organization for Economic Co-operation and Development, European Union, Conservation International, World Wildlife Fund, etc.) (Durham University, 2015; Fivaz and Gonseth, 2014; IUCN, 2015; Syfert et al., 2014). In India, SDM has been much related to an array of topics ranging from conservation of medicinal plants, ecologically important plants, threat from invasive species, distribution of flagship species etc. (Adhikari et al., 2012; Babar et al., 2012; Jaryan et al., 2013; Kanagaraj et al., 2011; Pramanik et al., 2018). The study, therefore, is an attempt to envisage the impact climatic variability on the distribution of *H. salicifolia* using Species Distribution Modeling. Under this purview study was designed under following objectives:

- Understanding the impact of climatic changes on distribution of *H. salicifolia* distribution in Central Himalayas
- Understanding potential bioclimatic variables affecting the future distributions of the species in Central Himalayas
- Assessing the challenges for species and specific concerns with respect to the changing climatic conditions
- Understanding the planning and development considerations for integration of species conservation approaches in shaping the habitat integrity for *H. salicifolia*.

2. Materials and methods

2.1. Study area and its ecological significance

Biodiversity hotspots in India includes the entire IHR (Myers et al., 2000), an important storehouse of innumerous threatened and endemic species. There are approximately 7000 flowering species reported from Central Himalayas (Gaur, 1999; Sundriyal and Sharma, 2016) that contributes to 31% of total floral diversity of the country. Around 119 species of flowering plants reported from Central Himalayas exhibit 2.35% endemism. 1503 genera belonging to 213 families of flowering plants, are present in different forest types, ranging from sub-tropical forests in upper Gangetic plain and Shiwaliks in the south to alpine vegetation of trans-Himalayan cold desert in the north of the region. Present study in Central Himalayas was focused on *H. salicifolia* in 24 locations in 12 major valleys (Dhyani et al., 2010) of the state (Appendix 1; Fig. 1). Study area in Uttarakhand falls between 29^0 30′ to 31^0 30′N Latitude and 77^0 30′ to 80^0 15′E Longitude. Altitude ranges from 300 to 7000 m (above mean sea level) occupying a total area 53,484 km^2 with a total population of 7 millions. Recorded forest area of the state is 38,000 square km^2, which constitutes 71.05% of its geographical area. Reserve forest constitutes 69.86%, Protected areas 26.01% and Unclassed forests are 4.13%. Per capita forest area is 0.376 ha (FSI, 2017; Uttarakhand Forest Statistics, 2013). The year has warm dry period, warm wet period and cool dry period. The annual rainfall varies about 1300 mm to 25,000 mm and average annual temperature range has been confined between 23 °C at 300 m and 13 °C at 2000 m. Snowfall occurs above 1800 m. Area is home to lush green forests with almost all major forest types and richness in species diversity (Champion and Seth, 1968; Roy et al., 2015). Topographic and climatic variability, and migration routes from adjacent phytogeographical zones etc. are responsible factors for this richness in diversity.

2.2. Hippophae salicifolia

In India, the species grows in the trans Himalayan zones of Jammu and Kashmir, Himachal Pradesh, Eastern Himalayan states, and Uttarakhand. The plant grows luxuriantly on sun facing steep slopes of Himalayan valleys. *H. salicifolia* being a pioneer species preferably grows in low soil moisture conditions of alluvial gravel present in wet landslides as well as river banks (Rongsen, 1992) (Fig. 2). Species in Uttarakhand grows as thorny shrub (Mana and Niti valleys) and also as tree (Gangotri, Yamunotri and Kedarnath valley). Plant prefers sandy and eroded soil and grows well on gravelly sand and stones on the banks of river or streamlets in forests.

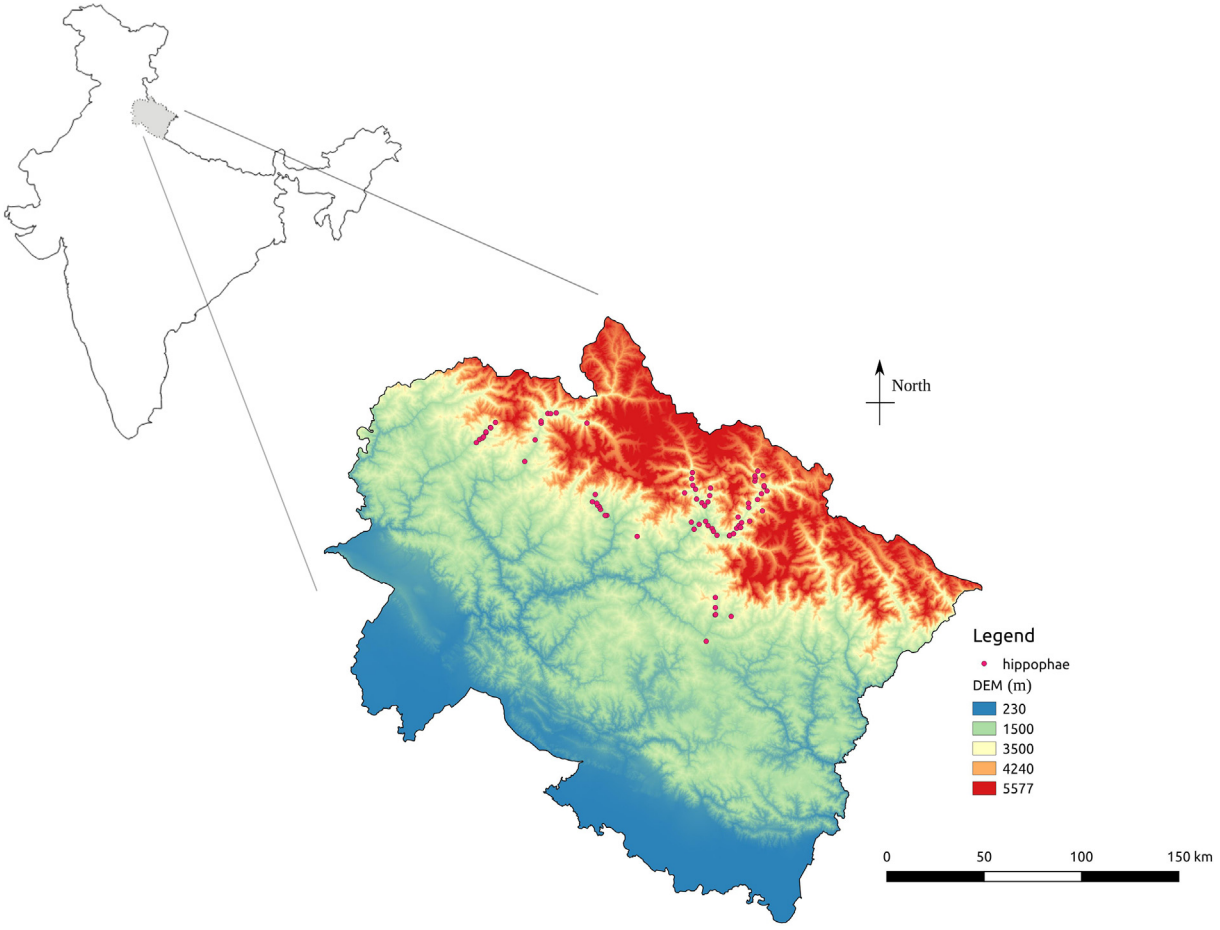

Fig. 1. Map showing the location of the study area in Uttarakhand state of India. The field monitored occurrences of the species *Hippophae salicifolia* are plotted as red dots on the elevation map of the Uttarakhand. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

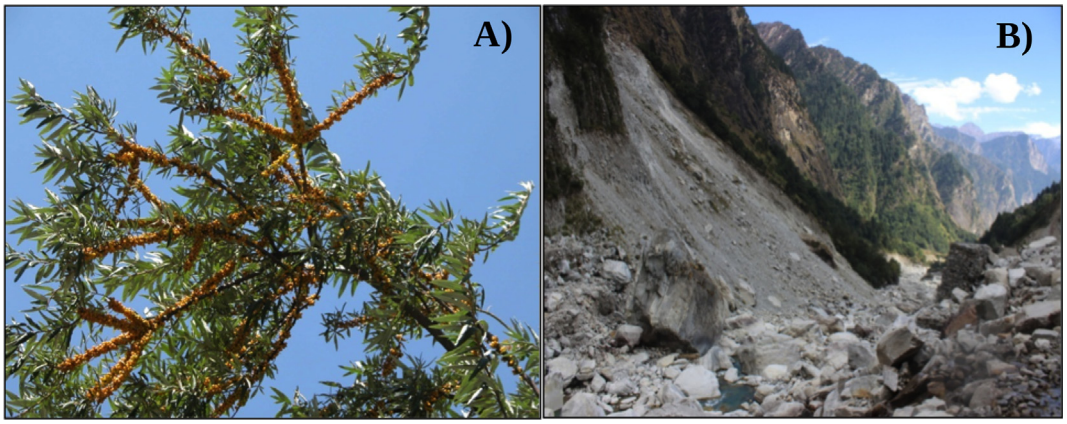

Fig. 2. A) *Hippophae salicifolia* plant and B) degraded habitat on the banks of river Alakhnanda, a major tributary of river Ganga in Central Himalayas, Uttarakhand India.

2.3. Species occurrence locations for SDM

Remote valleys of Central Himalayas were visited during post-monsoon periods (from June 2004 to July 2006 and were later visited again in 2016–2017). Survey was focused in 24 pockets distributed over 12 different valleys of Uttarakhand (Annexure 1). The occurrence locations of *H. salicifolia* were obtained from our extensive field surveys (Dhyani et al., 2010; Dhyani et al., 2013) and a total of 73 occurrence observations were used in the study (Fig. 1). Hand held GPS (Global Positioning System) gadget (make Trimble) was used to record the longitude and latitude of the occurrence locations. It was very daunting task to gather the species occurrence locations owing to the undulating terrain and poor accessibility on rivers banks (least access to many potential pockets of the species in different valleys).

2.4. Bioclimatic variables

Bioclimatic variables are more ecologically sensitive to demarcate physio-ecological tolerances of the habitats (Hijmans et al., 2005; Thompson et al., 2009) and used for SDM. The data of 19 bioclimatic variables (Table 1, predicted by CCSM4 (The Community Climate System Model Version-4, Gent et al., 2011)) for the present and future climate change scenarios were downloaded as raster layers from the WorldClim portal (http://www.worldclim.org/current) having a spatial resolution of 30 arc *sec* (equivalent to 900 m at equator and/or ~1 km). The variables having Pearson correlation (r), $r > |0.80|$ (significant at alpha = 0.05) were grouped together according to hierarchical cluster analysis (Fig. 3). One variable from each group was selected based on the calculated Variable Inflation Factors (VIF), in order to avoid the multi-collinearity among the data. The variables with VIF < 10 were considered in the study viz. – mean diurnal temperature range (bio2), temperature seasonality (bio4), mean temperature of driest quarter (bio9), precipitation of driest month (bio14), precipitation seasonality (bio15), and precipitation of warmest quarter (bio18) (Table 1). VIF values were calculated using *vif* function of *usdm* (Naimi, 2017) package of R (R Core Team, 2017). The summary of select predictor variables over the occurrence and background locations (used in MaxEnt) is plotted in Fig. 4.

2.5. Species distribution modeling

We employed MaxEnt (Maximum Entropy, version 3.3.3 k downloaded from http://www.cs.princeton.edu) (Phillips et al., 2004, 2006) algorithm called through *dismo* (version 1.1–4, Hijmans et al., 2017) package of R. MaxEnt was chosen owing to the presence-only kind of species occurrences that we got from field survey, moreover the model is best among other available SDMs and widely used for its excellent predictive performance even with relatively small number of occurrence locations ((Elith et al., 2006, 2011; Remya et al., 2015)). The model maximizes the entropy in estimating the probability distribution

Table 1
The relative contribution and spread of the bioclimatic variables which are used in MaxEnt (highlighted variables).

Variable code	Description	Units	Average of % contribution	Average value over species occurrences
bio1	Annual mean temperature	°C		
bio2	Mean diurnal temperature range	°C	17.5	11.21 ± 0.57
bio3	Isothermality (bio2/bio7)*100	–		
bio4	Temperature Seasonality (standard deviation *100)		8.4	627.28 ± 111.50
bio5	Max Temperature of Warmest Month	°C		
bio6	Min Temperature of Coldest Month	°C		
bio7	Temperature annual range (bio5-bio6)	°C		
bio8	Mean Temperature of Wettest Quarter	°C		
bio9	Mean Temperature of Driest Quarter	°C	8.9	8.20 ± 3.73
bio10	Mean Temperature of Warmest Quarter	°C		
Bio11	Mean Temperature of Coldest Quarter	°C		
bio12	Annual precipitation	mm		
bio13	Precipitation of Wettest Month	mm		
bio14	Precipitation of Driest Month	mm	32.2	24.62 ± 7.57
bio15	Precipitation seasonality (Coefficient of variation)		22.8	81.75 ± 9.61
bio16	Precipitation of Wettest Quarter	mm		
bio17	Precipitation of driest quarter	mm		
bio18	Precipitation of Warmest Quarter	mm	10.2	734.55 ± 156.40
bio19	Precipitation of Coldest Quarter	mm		

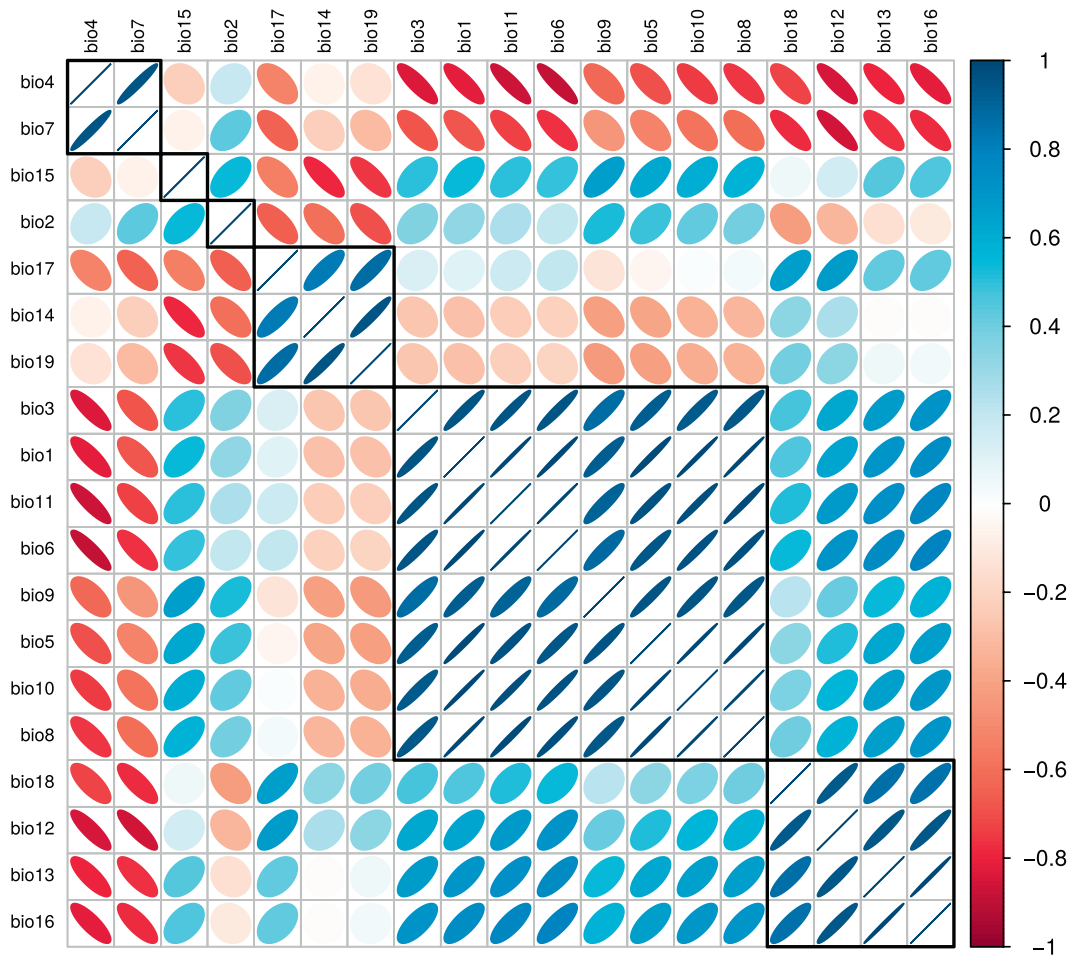

Fig. 3. Mutual correlations among the bio-climatic environmental variables. Blue colour indicates positive correlation, while red indicates negative correlation. The strength of Pearson correlation (r) increases from circle ($r = 0$) to ellipse (= intermediate) to line ($r = 1$). The variables having correlation, $r > 0.80$ are grouped together according to hierarchical cluster analysis. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

of the species with respect to environmental constraints. The principle of maximum entropy proposed by Jaynes (1957) is the fundamental idea behind the MaxEnt algorithm, which remains maximally non-committal to missing information and agrees with what is known.

MaxEnt model was ran with 10-fold cross-validation in order to over come the uncertainty and biases associated with the predictions. The number of background locations were set to 10,000 points within the extent of study area. The regularization multiplier value was set to 0.1, in order to avoid over fitting the model (Phillips et al., 2004). Linear and quadratic combinations of the predictor variables were used in the model to accommodate for the smaller sample size (Kumar et al., 2014). Duplicate occurrence points were removed, and rest of the model parameters were kept as defaults. Final results were based on the average of multiple runs from the cross-validation and the values are between 0 and 1, which can be interpreted as the probability of occurrences. We have calculated the model threshold based on the principle of maximizing the sensitivity and specificity (MSS) of logistic probabilities, which is very robust with presence-only type of data (Liu et al., 2013). Jackknife variable analysis was done to evaluate the relative significance of the bioclimatic variables, based on the model gain values when a particular variable was used in isolation. The habitat distribution for *H. salicifolia* under current conditions was projected to two time periods: 2050 (average for 2041–2060) and 2070 (average for 2061–2080). The predictions run into four representative concentration pathways (RCPs) used in the 5th assessment report of IPCC, RCP2.6, RCP4.5, RCP6.0 and RCP8.5. RCP2.6 represents the most climate friendly scenario, whereas RCP8.5 is the most extreme scenario.

2.6. Overlay analysis

The model projections for the future scenarios were entirely based on the climatic drivers. However, the actual habitat could vary due to the physical constraints which are unaccounted in the SDM. Based on our years of field observations, we found that, the species are mostly found within in ~1.25 km from the streams on both sides (the species *H. salicifolia* more dominantly grows in riparian zones of Alakhnanda, Bhagirathi and other major and minor tributaries of river Ganga (Dhyani, 2008; Dhyani et al., 2010, 2013)). The Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) with 30 m resolution (LPDAAC, 2018) was used to extract the natural stream networks (Fig. 5A) over the watersheds in the study area using the GRASS (Geographic Resources Analysis Support System) algorithm *r.stream.extract* (GRASS Development Team, 2017). A lateral buffer of width 2.5 km was assigned to represent the riparian zones and the area above the altitude of 1500 m was considered in the study (Fig. 5B). The resultant zone having an area of 5290 km^2 was superimposed on the species suitability map predicted by the SDM for further analyses.

3. Results and discussion

The presence, absence, as well as relative well-being of a species in a given environment happens to be an indicator of the overall health of

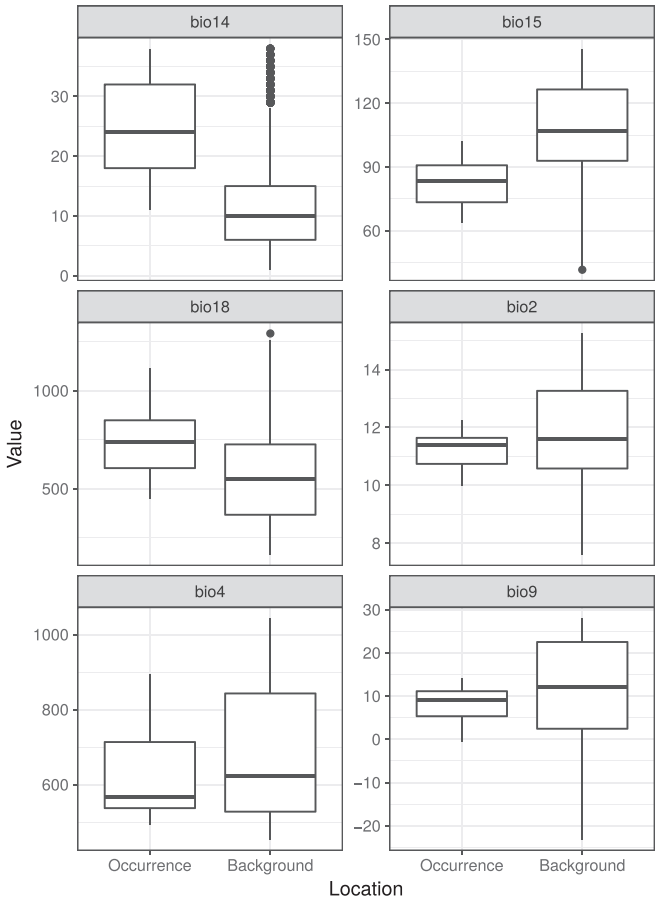

Fig. 4. Box-plots showing the spread of predictor bioclimatic variables sampled over the occurrence and background locations of the study.

the ecosystem. The need for this kind of consideration goes high in future in relation to fast changing ecological, climatic and economic scenario in the Indian Himalayan Region. While, considering such parameter and attributes in the riparian buffers of Bhagirathi and Alakhnanda the major tributaries of river Ganga, *Hippophae salicifolia* with traditionally established multipurpose utility (e.g. Ecological role in riparian buffers; slope stabilization ability; soil quality amelioration; traditional usage; value addition potential and greening the wastelands in Himalayas etc.) has proven high ecological and economic potential (Dhyani et al., 2007b).

The species distribution model fitted with current bioclimatic and species occurrence data has Area Under the Curve (AUC) value of 0.973 ± 0.015 (of 10-fold cross-validation), which reflects high rates of success in predicting the future habitat suitability distribution of *H. salicifolia* (Akhter et al., 2017; Deb et al., 2017b,a). AUC values > 0.9 indicate high accuracy, values varying from 0.7–0.9 indicate moderate accuracy, while values varying from 0.5 to 0.7 indicate low accuracy for results of habitat suitability (Elith et al., 2006; Stohlgren et al., 2010). Precipitation of the driest month (bio14), followed by precipitation seasonality (bio15) are the most important variables contributing to the distribution of the species (Table 1). The results are in consistence with Jackknife analysis.

Present day locations of the species are very much within the model predicted potential habitats (Fig. 6). The potential habitats limiting with in the resultant riparian buffers are estimated to be 2044.9 km^2 using the threshold of 0.048. Where as, the habitats of high probability (0.5–1) occupy an area of 421.9 km^2, accounting for 20.6% of potential habitat (Table 2). These potential valleys are Mana, Niti, Gangotri, Yamunotri, Bhyundhar in Central Himalayas (Annexure 1).

3.1. Distribution under future climate (2050 and 2070)

Results anticipate a considerable decline in the potential habitats of *H. salicifolia* in comparison with the present distribution both in terms of quantity (potential habitats) and quality (high probability habitats). The species is one of the key indicators of riparian health in high altitude areas (NEERI, 2017). By the year 2050 the species will lose 87.2% (average of four RCPs) of the potential habitats and by 2070 the results show a marginal gain of 30 km^2 with respect to 2050, in the riparian buffers. Where as, 80.6% of the high probable habitat (0.5 − 1) will be lost by 2050, and 75.6% by 2070, in comparison with the present conditions (Table 2 & Fig. 7). Also, the species are expected to scale new altitudes over the next decades in search of climate suitability. The average altitude of the potential habitat is projected to increase from 2813 ± 761 m to a maximum of 4278 ± 202 m for 2050 and 4485 ± 230 m for 2070 of RCP8.5 scenario. With in that, the high probable habitats are further expected to rise from 2542 ± 564 m to a maximum of 4280 ± 195 m for 2050 and 4510 ± 250 m for 2070 of RCP8.5 scenario (Table 2). High probable habitats in 2070 are on an average 30 m higher than potential habitats during the RCP8.5 scenario. Our model projections were consistent with the projections made on species growing in Himalayan region i.e. *Rhododendron species*

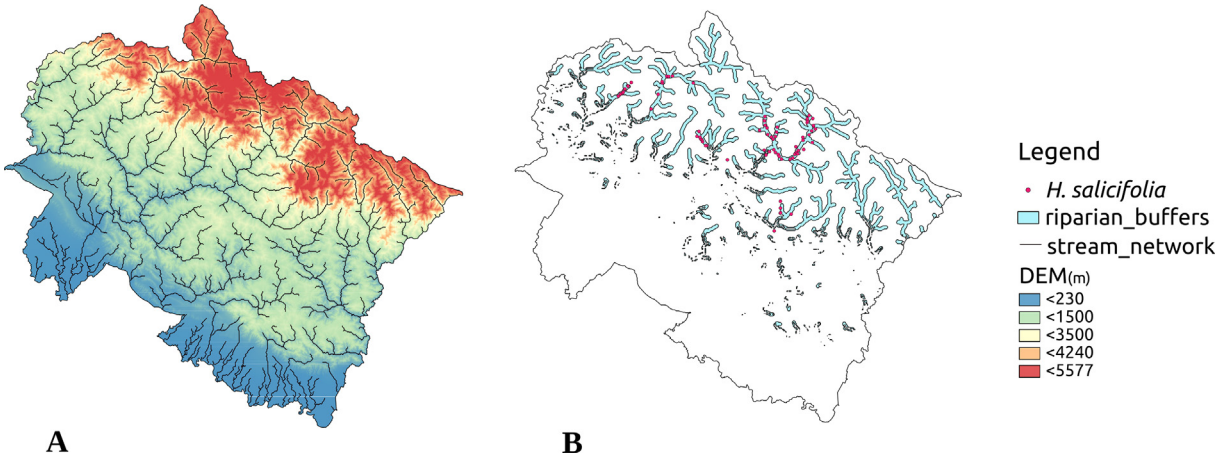

Fig. 5. A) Stream network of the study area. B) Riparian buffers of width 2.5 km above the 1500 m altitude. Field observed occurrences of *Hippophae salicifolia* are plotted in red dots and are found close to riparian zones of Alakhnanda, Bhagirathi and other important tributaries of river Ganga in upland areas of Central Himalayas. Maps were generated using QGIS 2.14. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

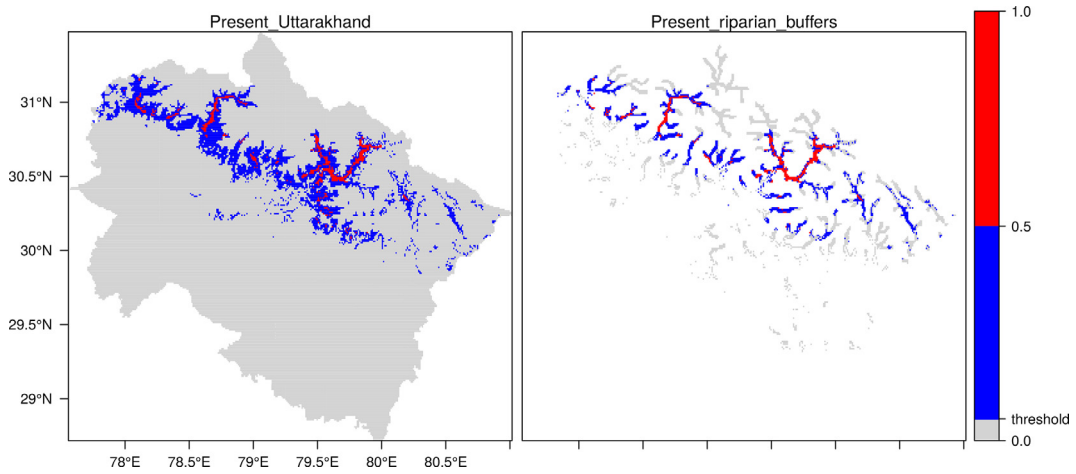

Fig. 6. Occurrence probability of *Hippophae salicifolia* in the present scenario over Uttarakhand territory and riparian buffers (above 1500 m, Fig. 5B).

Table 2
Influence of climate change on suitable area and altitudes of the *H. salicifolia*.

Scenario		(threshold-1)		(threshold-0.5)		(0.5–1)		
		Total potential area km^2	Altitude above sea level, m	Less probable area km^2	Altitude above sea level, m	High probable area km^2	Altitude above sea level, m	Loss in potential area with respect to present area, km^2, %
Present		2044.9	2813 ± 761	1623.1	2883 ± 790	421.9	2542 ± 564	
RCP2.6	2050	243.5	4003 ± 208	165.8	3986 ± 216	77.7	4040 ± 186	1801.4 (−88.1)
	2070	216.1	4008 ± 207	154.7	3989 ± 228	61.4	4056 ± 130	1828.8 (−89.4)
RCP4.5	2050	256.8	4172 ± 211	176.1	4163 ± 206	80.7	4193 ± 223	1788.1 (−87.4)
	2070	345.6	4230 ± 205	212.4	4223 ± 201	133.2	4239 ± 211	1699.3 (−83.1)
RCP6.0	2050	223.5	4137 ± 210	169.5	4124 ± 207	54.0	4178 ± 213	1821.4 (−89.1)
	2070	321.9	4254 ± 204	217.6	4252 ± 211	104.4	4261 ± 190	1723.0 (−84.3)
RCP8.5	2050	327.1	4278 ± 202	212.4	4277 ± 207	114.4	4280 ± 195	1717.8 (−84.0)
	2070	291.6	4485 ± 230	178.4	4471 ± 215	113.2	4510 ± 250	1753.3 (−85.7)

(Ranjitkar et al., 2014); *Betula utilis* (Bobrowski et al., 2018), Chinese Seabuckthorn *H. rhamnoides* subspecies *chinensis* (Huang et al., 2017). These studies also predicted a significant decline in habitats and estimated an upward shift in altitude. As the species is a pioneer, and already grows on rocky and disturbed soils or it can be grown in unfamiliar environmental conditions as its roots have mycorrhizal association that helps in fixing nitrogen to the soil, it is likely that the species can shift its habitat due to climate variability.

An upward migration of the alpine plant species is a change that has been linked to climate change affects in IHR (Panigrahy et al., 2010a,b; Singh et al., 2012). Sub-alpine and alpine zone extends from 2500 m amsl (above mean sea level) in Central Himalayas (Khanna and Chaturvedi, 2000). Vegetation of alpine zones reflect the characteristic climatic adaptation as per extreme environmental conditions. Distribution of species in alpine areas is administered by extreme climatic and edaphic parameters (Kershaw, 1973). *H. salicifolia* is an indicator species and its relative well being or presence and absence in the given environment indicate to the overall health of the riparian zones of Central Himalayas. As per SDM results the species might migrate to higher elevations, but its decline will lead to the loss of overall health of riparian buffers in its present occurrence zones.

3.2. Contribution of bio14

Analysis shows that bio14 (precipitation of the driest month) significantly influences the habitat distribution by 32.2% in comparison with rest of the variables. Bio14 ranges between 0 and 38 mm with an average of 24.62 ± 7.57 mm over the occurrence locations of the *H. salicifolia*. Positive response between the bio14 and probability of species occurrence (Fig. 8) will guide the conservation strategies in identification of suitable pockets of the habitats. Average of bio14 over the high probable habitats (0.5–1) decreases from 24.6 ± 7.3 mm to a minimum of 16.1 ± 2.3 mm for the period 2050 and to 15.5 ± 2.0 mm for 2070 of RCP6.0. However, on an average the values drop significantly from 24.6 mm in present scenario to 16.9 mm (average of all RCPs) for 2050 and to 17.3 mm (average of all RCPs) for 2070. The decline in the precipitation of driest months in future decades is clearly influencing the loss of habitat. Singh (2008) mentioned that, precipitation during the dry seasons plays an important role in affecting the yield and areas receiving < 200 mm of total precipitation in the season, may require additional irrigation to maximize the yield.

Significant variation in driest/winter period temperature and rainfall may restrict the distribution of *H. salicifolia* species in Central Himalayas. Long term analyses will be needed to assess and understand the sensitivity of species distribution across Uttarakhand, taking into account more relevant climatic and environmental variables.

3.3. Future challenges

The distribution of *H. salicifolia* over central Himalayas is simulated entirely based on the climate drivers. Nevertheless, the predictions would have been more realistic, if variables like – land use land cover changes, variable of tree physiology, competition, ability to disperse, etc. are taken into account (Deb et al., 2017a; Dhyani et al., 2007a). The major challenge in terms of SDM is the assimilation of various environmental data from diverse sources into the SDM platform, and the prediction of future variability in such data through global climate models or socio-economic models etc. adds value to the habitat suitability modeling. Considering the limitations, the study is a preliminary but relevant assessment on habitats of *H. salicifolia*. The need for this kind of consideration goes high in future in relation to fast changing ecological, climatic and economic scenario in the Indian Himalayan

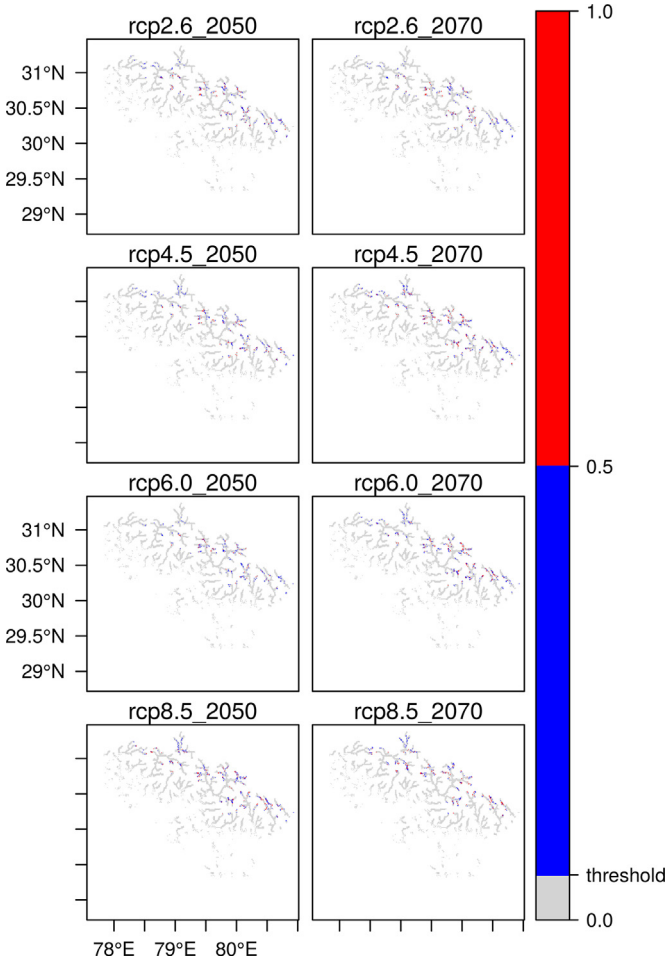

Fig. 7. Occurrence probability of *Hippophae salicifolia* in future periods 2050 and 2070, according to the IPCC RCPs.

Region.

Extreme natural events due to floods, cloudbursts and landslides have severely affected the species habitat in last few decades. Rapid infrastructural development has led to significant impact of many species growing close to human settlements. The potential habitats of *H. salicifolia* in Alaknanda and Bhagirathi river basins also have many commissioned or proposed Hydro Electric Projects (HEP) (Rajvanshi et al., 2012). Other developmental activities such as continuous road construction, broadening and repairing activities along with recent development of all weather roads had significant impact on habitat destruction. Impacts are clearly visible in Mana, Niti, Bhyundhar, Kedarnath and other valleys.

Study on demographic structure, density and harvesting of *H. salicifolia* in five major valleys (Gangotri, Yamunotri, Niti, Mana and Bhyundhar/valley of flower) along the riparian zones of river Ganga (Bhagirathi, Dhauliganga, Alakhnanda and Pulna) and Yamuna (Yamunotri) was undertaken. Analysis shows that density, regeneration patterns and size distribution of *Hippophae* varies considerably in all the valleys. It was concluded that unsustainable harvesting from plants for fuel, fencing and fruits are also reasons of habitat destruction for the species (Dhyani et al., 2013). The *H. salicifolia* being a pioneer deciduous species and an important nitrogen fixer that improves soil fertility, its loss might lead to habitat instability for other seral and climatic climax species.

4. Conclusion

The potential distribution and habitat suitability of *H. salicifolia* in Central Himalayas was found to have reached a crucial stage that is a huge cause of concern for the conservationists, state forest department and protected area managers. Present and future suitability maps along with influential bioclimatic variables can be of significant help to MoEF &CC (Ministry of Environment Forest and Climate Change, Govt. of India) as well State Forest Department of Uttarakhand and states in IHR (Indian Himalayan Region) where the species grow (Himachal Pradesh, Kashmir, Sikkim, Arunachal Pradesh etc). Research and Development organizations in the country and across the borders may take the results of the study for planning long term conservation initiatives related to the species. Species has been already listed by MoEF&CC in various documents as potential species for restoring wastelands, barren lands in IHR and is an excellent species to support EcoDRR (ecosystem based disaster risk reduction) and provide nature based solutions. The species has high potential to generate alternative livelihood opportunities to locals of higher Himalayan traditional and indigenous communities. If properly protected and harnessed the species can provide potential nutritional support to locals as well as downstream communities. Considering the ecological, economic background of the species, SDM is a useful method to provide evidences of climate change on suitability of habitat. The study area demarcated for the study as ‘ suitable climate space’ for present and future would help in in-situ and ex-situ conservation of *Hippophae salicifolia* species. By protecting the *H. salicifolia* growing pockets and developing agri-horti and agroforestry models by introducing the species in cropland bunds. Using the species in slope stabilization landslides can be managed and species conservation can be planned by active community participation. The projected habitat suitability under future climatic scenarios may help planning the conservation strategies for *H. salicifolia* in Central Himalayas, and plan slope stabilization activities and to maintain the health of riparian zones. In long run, as already mentioned in the discussion, the species has been proven to help providing sustainable economic opportunity to locals by ex-situ conservation practices.

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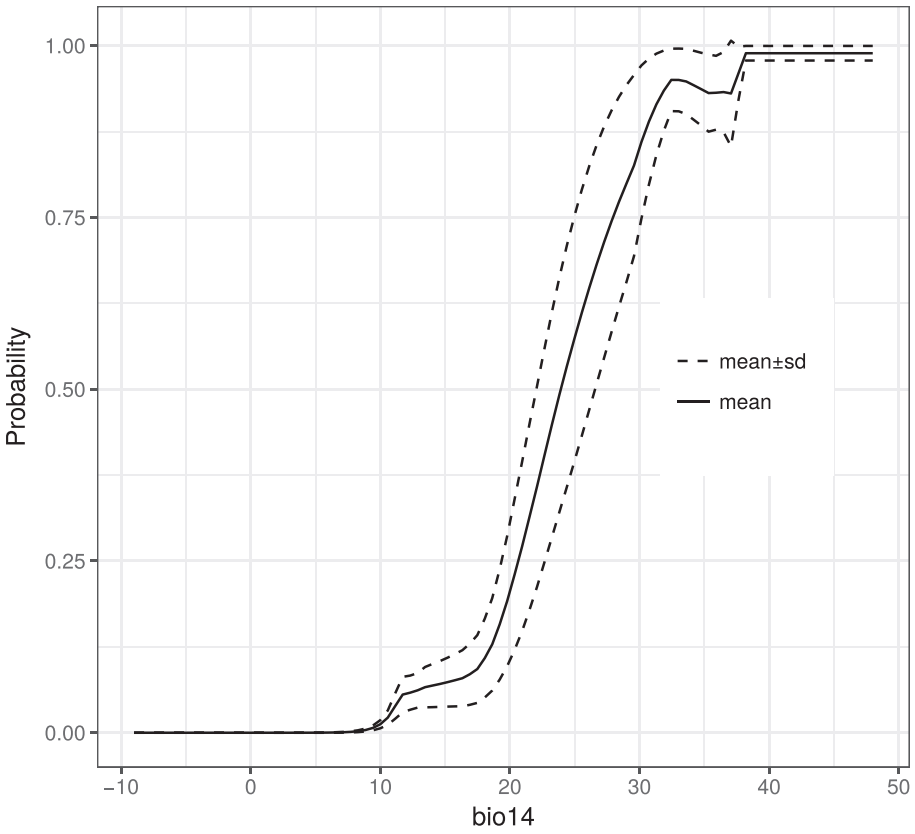

Fig. 8. The curve showing the logistic prediction of the *Hippophae salicifolia* when considered bio14 alone as a variable, while keeping all other predictor variables at their average sample value. The solid line shows the mean response of multiple runs of MaxEnt and and the dashed line represents the one standard deviation. (bio14 - precipitation of driest month).

Appendix 1. Appendix

Valley	No.	Location/village	Altitude (m)	Latitude	Longitude
Mana	1	Mana	3317	30°46′15.09”N	79°29′51.43″E
	2	Badrinath	3122	30°44′36.47”N	79°29′38.16″E
	3	Binakuli	2867	30°42′48.85”N	79°29′59.34″E
	4	Hanumanchatti	2707	30°41′45.70”N	79°30′51.69″E
Kheeron	5	Kheeron	3121	30°40′46.31”N	79°27′22.76″E
Mana	6	Lambaggar	2239	30°39′6.72”N	79°31′9.14″E
	7	Pandukeshwar	1912	30°38′5.00”N	79°32′50.55″E
Bhyundhar	8	Govind Ghat	1717	30°37′15.31”N	79°33′42.10″E
	9	Pulna	2219	30°38′19.69”N	79°34′44.05″E
	10	Bhyundhar	2475	30°40′2.54”N	79°35′18.80″E
	11	Ghangariya	3101	30°42′3.59”N	79°35′34.12″E
	12	Joshimath	2092	30°33′2.50”N	79°34′0.26″E
Niti	13	Barhgaon	2181	30°31′6.48”N	79°36′3.83″E
	14	Dhak	2265	30°30′20.58”N	79°36′29.15″E
	15	Tapovan	2186	30°29′15.72”N	79°37′35.91″E
	16	Reni	2036	30°29′6.95”N	79°41′30.42″E
	17	Reni 2	2047	30°29′15.49”N	79°41′37.30″E
	18	Lata	2354	30°29′41.36”N	79°42′50.14″E
	19	Suki	2408	30°31′10.64”N	79°43′47.80″E
	20	Surainthota	2178	30°31′54.65”N	79°44′33.83″E
	21	Tolma	2656	30°31′23.59”N	79°45′4.39″E
	22	Bhalgaon	2984	30°34′13.00”N	79°44′15.80″E
	23	Pangrasu	2824	30°32′43.43”N	79°45′22.53″E
	24	Fagti	3916	30°33′6.06”N	79°47′54.58″E
	25	Jumma	3166	30°36′47.31”N	79°47′37.51″E
	26	Jhelam	3278	30°37′57.73”N	79°47′31.65″E
	27	Dunagiri	3570	30°35′54.35”N	79°51′55.87″E
	28	Garpak	3209	30°38′58.12”N	79°50′23.61″E
	29	Kosa	2857	30°40′33.61”N	79°51′38.31″E

30	Malari	3023	30°41′18.01”N	79°53′23.06″E
31	Kailashpur	3046	30°42′25.60”N	79°52′28.87″E
32	Mahar gaon	3157	30°42′41.35”N	79°52′27.09″E
33	Farkya	3266	30°43′55.10”N	79°49′32.35″E
34	Bampa	3313	30°44′37.20”N	79°49′41.70″E
35	Gamsali	3362	30°45′20.50”N	79°49′33.95″E
36	Niti	3470	30°46′41.13”N	79°50′28.08″E
37	Gurguti	4220	30°45′26.63”N	79°52′7.11″E
38	Parsari	2436	30°31′54.31”N	79°34′46.03″E
39	Sailang	2250	30°32′13.79”N	79°31′58.78″E
40	Helang	1819	30°30′53.85”N	79°30′22.53″E
41	Urgam	2225	30°32′49.88”N	79°29′30.99″E
42	Maikhanda	1605	30°34′39.67”N	79°2′51.23″E
43	Fata	1624	30°34′39.73”N	79°2′18.85″E
44	Sersi	1780	30°36′16.38”N	79°0′51.99″E
45	Rampur (Nyalsu)	1741	30°37′0.99”N	79°0′30.55″E
46	Sitapur (Nyalsu)	1707	30°37′21.21”N	78°59′57.97″E
47	Sonprayag	1910	30°37′58.01”N	78°59′41.07″E
48	Triyuginarayan	2322	30°38′21.92”N	78°58′17.14″E
49	Tausi	2809	30°40′20.47”N	78°59′12.13″E
50	Chopta	2915	30°28′57.47”N	79°12′24.99″E
51	Gwaldam	1906	30°0′21.92”N	79°34′11.65″E
52	Ghes	2529	30°7′10.06”N	79°42′4.98″E
53	Mundoli	2186	30°7′33.49”N	79°37′1.29″E
54	Lohajung	2329	30°7′41.22”N	79°37′9.75″E
55	Kuling	2309	30°9′33.87”N	79°37′5.43″E
56	Wan	2450	30°12′19.83”N	79°37′5.48″E
57	Bhatwari	1715	30°49′15.94”N	78°36′57.16″E
58	Gangnani	2325	30°55′6.82”N	78°40′13.69″E
59	Dabrani	2286	30 59′37.80”N	78°42′9.00″E
60	Sukki	2647	31°0′11.73”N	78°42′5.76″E
61	Harsil	2522	31°2′15.16”N	78°44′13.35″E
62	Bagori	2505	31°2′12.72”N	78°45′6.96″E
63	Dharali	2531	31°2′24.63”N	78°46′53.57″E
64	Gangotri	3067	30°59′38.95”N	78°56′34.44″E
65	Sayanachatti	1811	30°54′22.34”N	78°21′40.61″E
66	Ranachatti	2087	30°55′13.98”N	78°22′42.10″E
67	Badiya	2115	30°55′35.66”N	78°23′35.99″E
68	Hanumanchatti	2071	30°55′56.92”N	78°23′57.63″E
69	Naradchatti	2234	30°57′4.03”N	78°24′42.83″E
70	Phoolchatti	2280	30°57′16.36”N	78°24′43.27″E
71	Jankichatti	2551	30°58′29.13”N	78°26′6.25″E
72	Kharsali	2570	30°58′22.18”N	78°26′15.11″E
73	Yamunotri	3208	30°59′50.64”N	78°27′43.21″E

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